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RESEARCH MEMORANDUM

DETERMINING THE OPTIMAL LEVEL OF GRADUATE EDUCATION FOR NAVAL OFFICERS

Donald J. Cymrot

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This memorandum explores ways to measure the marginal benefits and marginal costs of graduate education to help allocate the Navy's educational resources. A major portion of the analysis deals with the difficult problems that arise in the measurement of the marginal benefits. It also discusses the components and measurement of the marginal cost and concludes with a brief analysis of the way in which the Navy currently allocates its graduate education resources.

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1. Enclosure (1) is forwarded as a matter of possible interest.

2. This Research Memorandum is the first of several intermediate products from a study of officer graduation needs. It points out difficulties in determining the optimal level of graduate education for naval officers. Although this optimal cannot currently be identified, several ways are suggested to help estimate it. Two of them will be subjects of reports in the near future.

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DETERMINING THE OPTIMAL LEVEL OF GRADUATE EDUCATION FOR NAVAL OFFICERS

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ABSTRACT

This memorandum explores ways to measure the marginal benefits and marginal costs of graduate education to help allocate the Navy's educational resources. A major portion of the analysis deals with the difficult problems that arise in the measurement of the marginal benefits. It also discusses the components and measurement of the marginal cost and concludes with a brief analysis of the way in which the Navy currently allocates its graduate education resources.

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INTRODUCTION

The optimal amount of graduate education that the Navy should provide its officers is the amount at which the marginal benefit and marginal cost for the Navy are equal. The Navy's problem in determining this optimal is similar to the one faced by a firm trying to decide how much training to provide for its workers, but is different from the one faced by an individual trying to decide how much schooling to seek for himself. The problem faced by the individual has been studied extensively ([1] and [2], for example) and primarily involves measuring the gain in earnings that results from additional schooling. The increased earnings for workers receiving additional schooling is relevant for employers (i.e., a private firm or the Navy); it is one component of the marginal cost. Determining the marginal benefit for employers requires measuring the gain in the productivity of workers resulting from the increased schooling.

One reason the employer's problem in this area has received less attention than the individual's is that measuring a worker's productivity is difficult. This difficulty is twice compounded in the case of Naval officers. Officers are managers; they produce output indirectly by making others more productive, and the output of the Navy is national defense, which is not readily amenable to unit measurement and valuation. Given these difficulties, it is not likely that an exact measure of productivity can be devised. Without such a measure, the marginal benefit of graduate training cannot be measured directly. This inability should not be confused with the idea that differences in productivity among officers do not exist. Not all officers rise through the ranks as fast or as far. If officers that get promoted the fastest and to the highest ranks are assumed to be the most productive, differences in career paths among officers imply differences in the level of productivity. If differences in productivity can be observed, albeit only indirectly, information about the marginal benefit of graduate education can be derived.

This memorandum explores ways to measure the marginal benefits and marginal costs of graduate education to help allocate the Navy's educational resources. A major portion of the analysis deals with the difficult problems that arise in the measurement of the marginal benefits. It also discusses the components and measurement of the marginal cost. The memorandum concludes with a brief analysis of the way in which the Navy currently allocates its graduate education resources.

MEASURING MARGINAL BENEFITS

A SIMPLE MODEL OF THE MARGINAL BENEFITS

The total value (V) of an officer's career to the Navy is the present discounted value of his productivity or marginal product.

$$V = \sum_{t=1}^{T} \frac{MP_t}{(1 + r)^t} , \tag{1}$$

where MP_t = marginal product in year t

T = length of career

r = discount rate for the Navy.

Suppose that the productivity of an officer depends entirely on his rank R, so that his marginal product for each year in a rank is the same, but it increases after each promotion. An index of productivity at each rank, a_i, can be defined as ratio of the marginal product at rank i to the MP at the lowest rank, MP_1.

$$a_i = \frac{MP_i}{MP_1} , \tag{2}$$

where i varies from 1 to n, and n is the maximum rank. If i = 1, then a = 1, and for all other ranks a is greater than 1. Using equation 2, equation 1 can be rewritten as

$$V = MP_1 \sum_{t=1}^{T} \frac{a_{i,t}}{(1 + r)^t} . \tag{3}$$

The subsequent analysis is simplified without affecting the basic results by assuming r = 0, so that

$$V = MP_1 \sum_{t=1}^{T} a_{i,t} . \tag{3a}$$

The marginal benefit to the Navy of providing graduate education to its officers is the resulting increase in the total value of an officer. The marginal benefit is measured as the difference in the total values.

$$MB = V_g - V_n , \tag{4}$$

where the subscripts g and n denote officers with and without graduate training. Once an officer receives graduate training, it is not possible to observe V_n. This problem can be overcome by assuming that selection for graduate training is made at random, that is, on average the pregraduate training careers of graduate trained and non-graduate trained officers is the same.[1] In this case, V_n can be estimated by observing the careers of officers not receiving graduate training.

Equation 4 can be rewritten

$$MB = MP_1 \left(\sum_{t=1}^{T} a_{g,i,t} - \sum_{t=1}^{T} a_{n,i,t} \right) . \tag{5}$$

where $a_{g,i,t}$ is the productivity index for a graduate trained officer of rank i at time t, and $a_{n,i,t}$ is the productivity index of other officers of rank i at time t.

The marginal benefit is positive as long as the sum of the productivity indexes is greater for those receiving graduate training. Measuring differences in the productivities within rank may be particularly difficult; for the moment assume that graduate training affects the promotion rate but not within-rank productivity. Graduate educated officers spend fewer years in the less productive lower ranks and more years in the higher productivity upper ranks.

---

1. If selection for graduate training is not random, this assumption introduces selectivity bias into the calculation of the marginal benefit. A strategy for dealing with this possible bias is discussed below.

Let $y_{g,i}$ and $y_{n,i}$ be the number of years served in rank i for each group. These y's are inversely related to the promotion rate; the faster an officer gets promoted to the next rank, the smaller the y for the previous rank. Assume that officers receive graduate training at rank k. Equation 5 can be rewritten and expanded using y notation.

$$MB = MP_1[(a_k y_{g,k} + a_{k+1} y_{g,k+1} + \dots + a_m y_{g,m}) - (a_k y_{n,k} + a_{k+1} y_{n,k+1} + \dots + a_m y_{n,m})] \quad . \tag{6}$$

Note that the subscripts in equation 6 begin with rank k. All terms before rank k cancel out because of the assumption that the careers and productivity before graduate study are identical.

Now assume that within each group the number of years spent in ranks k through $m - 1$ are the same.

$$y_{g,k} = y_{g,k+1} = \dots = y_{g,m-1} = y_g \tag{7a}$$

$$y_{n,k} = y_{n,k+1} = \dots = y_{n,m-1} = y_n \ . \tag{7b}$$

The number of years spent in the maximum rank m is

$$y_{g,m} = T - (m - 1 - k)y_g - T_k \tag{8a}$$

$$y_{n,m} = T - (m - 1 - k)y_n - T_k \tag{8b}$$

where T_k is the total number of years of service prior to graduate training.

In this model, graduate training accelerates promotion. This can be represented by assuming

$$y_g = \alpha y_n \quad , \tag{9}$$

where $0 < \alpha < 1$.

Substituting equations 7 through 9 into equation 6 gives

$$MB = MP_1(1 - \alpha)y_n[(m - 1 - k)a_m - (a_k + \ldots + a_{m-1})] \quad . \tag{10}$$

Notice that on each side of the negative sign in the brackets there are $(m - 1 - k)$ terms. Because a_m is the largest a_i, the bracketed is positive.

Now assume that the rate that productivity increases across ranks is a constant, β, so that

$$a_i = a_{i-1}(1 + \beta) \quad . \tag{11}$$

For example, if $\beta = 0.1$, this assumption implies that a lieutenant junior grade is 10 percent more productive than an ensign, a lieutenant is 10 percent more efficient than a junior grade, and so on. This productivity relationship can be summarized as

$$a_i = (1 + \beta)^{i-1} \quad . \tag{12}$$

Substituting equation 12 into equation 10 and simplifying gives

$$MB = MP_1(1 - \alpha)y_n(1 + \beta)^k \sum_{i=1}^{n-k}[(1 + \beta)^{n-k} - (1 + \beta)^{i-1}] \quad . \tag{13}$$

Equation 13 shows that the size of the marginal benefit depends on the promotion rate and the growth rate of productivity. The promotion rate is inversely related to the relative time in rank parameter α. A decrease in α implies the differential in promotion rates is increasing, and, consequently, the marginal benefit increases. Also, as the growth rate in productivity β increases, the marginal benefit increases.

The simple model makes several restrictive assumptions that are relaxed in the next section. This model has some use to policy makers, because it focuses on the role of promotion rates in determining the marginal benefits. Promotion rates are the most readily observable variable in this analysis. If graduate trained officers are not promoted faster and further than other officers, the benefits from such training are likely to be difficult to perceive. There is evidence that graduate trained officers on average have the faster promotion rates. According to the March 1985 Officer Master File, the proportion of officers with graduate training increases with rank. For example, the proportion of unrestricted line officers with graduate degrees is 35 percent for lieutenant commanders, 51 percent for commanders, 59 percent for captains, and 64 percent for flag officers. If the proportion of officers receiving graduate education in a particular entry cohort is constant or increasing over time, the rising proportion who reach higher ranks indicates that officers with such education are promoted faster and to higher ranks than those officers without it.

MODIFICATIONS OF THE BASIC MODEL

Some of the restrictions made in the simple model are relaxed in this section.

INTRARANK PRODUCTIVITY DIFFERENCES

Suppose that graduate training raises the productivity of officers within a rank. Specifically assume that

$$a_{g,i} = (1 + \beta)^{i-1} \tag{14a}$$

$$a_{n,i} = \gamma_i a_{g,i} = \gamma_i (1 + \beta)^{i-1} \quad , \tag{14b}$$

where $0 < \gamma_i \leq 1$. Substituting equation 14 along with equations 7 through 9 into equation 5 gives

$$\begin{aligned} MB = MP\Bigg\{ & y_n \alpha \left[(1 + \beta)^{k-1} + \ldots + (1 + \beta)^{m-2}\right] \\ & + \left[\hat{T} - (m - 1 - k)\alpha y_n\right] (1 + \beta)^{m-1} - y_n \left[\gamma_k (1 + \beta)^{k-1} + \ldots \right. \\ & \left. + \gamma_{m-1} (1 + \beta)^{m-2}\right] - \left[\hat{T} - (m - 1 - k) y_n\right] \gamma_m (1 + \beta)^{m-1}\Bigg\} \end{aligned} \tag{15}$$

where $T = T - T_k$. Now suppose that the gain from graduate education is constant across all ranks. This assumes that the γ's are all equal. Equation (15) can be rewritten as follows:

$$\begin{aligned} MB = MP_1\Bigg\{ & y_n(\gamma - \alpha)(1 + \beta)^k \sum_{i=1}^{m-k} \left[(1 + \beta)m - k(1 + \beta)^{i-1}\right] \\ & + \hat{T}(1 + \beta)^{m-1}(1 - \gamma)\Bigg\} \quad . \end{aligned}$$

This formula is a generalization of equation 13, in which $\gamma = 1$. In this model, an increase in the parameter γ leads to a decrease in the marginal benefit. This means that the productivity differential widens the increase in marginal benefits.

CAREER LENGTH AS A VARIABLE

In the simple model, all officers are assumed to remain in the Navy for the same number of years. In fact, they do not. Different lengths of service, by themselves, do not necessarily undermine the value of the simple model. If the distribution of the length of service is the same for graduate trained and other officers, officers could be grouped by their expected length of service, and the marginal benefit could be calculated for each group. The problem with the simple model is that the length of service may be influenced by the level of education. In other words, graduate education may induce officers to remain in the Navy longer or leave earlier than those without it. If this is the case, variable career lengths need to be built into the model. Two questions are addressed: what is the effect of graduate education on the choice of career length and what is the effect of different career lengths on the marginal benefit?

The standard model for addressing questions about career length in the Navy is the annualized cost of leaving (ACOL) model [3]. The motivating assumption in the ACOL model is that an individual remains in the Navy as long as the net benefit is positive. The net benefit of remaining A_t is defined as the expected discounted present value of utility of staying in the Navy for an additional year minus the expected discounted present value of utility of leaving. Utility is assumed to depend on total compensation, which includes: military base pay, allowances, bonuses, military tax breaks, and the value of the military pension; civilian wages, fringe benefits, and pension; and the taste or distaste for military life. If there are no systematic differences in the taste for military service between graduate trained and other officers, the taste term can be dropped from this analysis, and the focus can be placed on factors that affect expected income of Navy versus civilian life.

$$A_t = PVN_t - PVC_t \quad , \tag{16}$$

where PVN_t and PVC_t are the discounted values of income for the Navy and civilian employment. The t subscripts on the variables suggest that their value can change every period. Thus, the decision when to leave the Navy is made each period. In this model, a period is not necessarily a year; commitments to the Navy are often made for longer than a year. Each year spent in graduate studies brings a service obligation with it. For example, if an officer spends 2 years at the Naval Postgraduate School, he is obligated to remain in the Navy for an additional 3 years [4].

According to this model, the officer remains in the Navy as long as A_t is positive. Because not all officers are in the same position or face the same prospects, both in the Navy and civilian sector, there is a distribution rather than a single value for A_t. The officer retention rate is the proportion of individuals for whom $A_t > 0$. For a group of officers, a higher retention rate implies a longer average career length.

Graduate education influences the career length through its effect on an officer's prospects both in and out of the Navy (i.e., PVN and PVC). The relationship between graduate education and PVN is indirect. There are several intervening variables. First, graduate education raises the productivity of officers. Second, productivity influences the rate of promotion, i.e., a more productive officer gets promoted faster. Third, the promotion rate is positively correlated with PVN. An analysis of each of these relationships is necessary to understand why different officers may be affected differently by graduate education.

Assume that there is a production function that tells the amount of Navy output N an officer produces as a result of having such inputs as schooling (s), experience (e), ability (a), and a vector of other factors (X). The X vector could include such factors as rank and designator.

$$N = N(s, e, a, X) \quad . \tag{17}$$

The derivative of this production function with respect to schooling is the increase in productivity resulting from extra schooling or the marginal product of schooling MP_s. According to the law of diminishing returns, this derivative is positive and diminishing. In other words, each extra year of schooling (e.g., graduate training) increases productivity, but by smaller and smaller amounts. If the N production function is nonseparable, the MP_s would also depend on the e, a, and X.

$$MP_s = MP_s\,(s, e, a, X) \quad . \tag{18}$$

In this case, the amount that graduate education improves the productivity of an officer varies. This is an important point. The productivity gain is not the same for all officers. Individual characteristics such as inherent ability or group characteristics such as designators can influence the size of the gain from graduate education.

The second component of this analysis is the relationship between productivity gain and promotion. Presumably, more productive officers get promoted faster. The promotion rate δ is positively related to the level of productivity; however, the promotion rate depends on other factors. Promotion in the Navy is limited by the reverse pyramid structure of the officer corps. There are fewer officers in each higher rank.[1]

Suppose $o_{i,t}$ is the number of officers eligible for promotion at rank i at time t, and $b_{i,t}$ is the number of billets available for promotion in rank i at time t. The proportion of officers for a given rank likely to get promoted is

$$\eta_{i,t} = \frac{b_{i+1,t}}{o_{i,t}} . \tag{19}$$

Now define $B_{i,t}$ as the total number of billets authorized in rank i at time t. The shape of the pyramid structure can be characterized by the rates of authorized billets in successive ranks.

$$\lambda_{i,t} = \frac{B_{i+1,t}}{B_{i,t}} . \tag{20}$$

For example in 1985 among unrestricted line officers there were 4,184 authorized lieutenant commander billets and 1,885 authorized commander billets. In that year, λ_5 equaled 0.45 (i.e., 1,885/4,185). The number of billets available for promotion at time t depends on attrition from that rank. Suppose $\Theta_{i,t}$ is the proportion of officers of rank i at time $t - 1$ who remain in that rank at time t, then

$$b_{i,t} = \Theta_{i,t}B_{i,t} . \tag{21}$$

Attrition from a given rank is $1 - \Theta_i$. Let $o_{i,t}$ be the total number of officers of rank i at time t. Now suppose that all billets are

1. There are actually more lieutenants (O-3) than either ensigns or lieutenant junior grades. On average, however, an officer is only in the two lower ranks for 2 years apiece but is in the lieutenant rank for 5 years. Promotion from the lower ranks to O-3 is competitive and can be limited by billet availability.

filled so that $B_{i,t} = O_{i,t}$. The number of officers eligible for promotion is

$$o_{i,t} = (1 - \Theta_{i,t})O_{i,t} = (1 - \Theta_{i,t})B_{i,t} \quad . \tag{22}$$

Substituting equations 20 and 21 into equation 19 gives the relationship

$$\eta_{i,t} = \frac{\Theta_{i+1,t}}{(1 - \Theta_{i,t})}\lambda_{i,t} \quad . \tag{23}$$

Increases in attrition or expansion in the relative number of upper rank billets increases the proportion of officers who get promoted to the next rank. As this proportion increases, the promotion rate also increases.

The promotion rate for a particular officer depends on both the productivity and these force characteristics. If an officer's productivity improves as a result of his graduate training, this training increases his promotion rate. The extent of the increase depends on his personal characteristics and the force structure characteristics. Not all officers' productivity increases by the same amount as a result of the graduate training, and not all force structures are equally conducive to promotion. To summarize the promotion rate, δ is a function of both personal characteristics and force structure characteristics.

$$\delta = \delta(MP_s, e, a, X, \lambda, \Theta) \quad , \tag{24}$$

where all the derivatives are positive.

The relationship between PVN and the promotion rates is the final component of this analysis. Assume that other compensation is proportional to base pay. In this case, only two variables--rank and years of experience--affect total military compensation. These two variables are intertwined. At a given time, the number of years of experience exerts a strong influence on rank. Most officers get promoted within a particular time period or zone. So, for instance, most officers with 7 years of service are lieutenants. Over the entire career, length of service is strongly influenced by rank, because forced retirement from the Navy is related to rank, and because total compensation is higher at higher ranks. Since A_t is analyzed from the perspective of the entire career, the path of ranks over time is the primary determinant of variations in PVN. A convenient way to capture the path of ranks over time is the rate of change of rank or the promotion rate.

The link between graduate education and the present value of remaining in the Navy is completed. Graduate education makes officers more productive. The extent of the increase in productivity depends on other personal characteristics. A more productive officer is more likely to get promoted, but an officer's promotion rate also depends on characteristics of the force structure, which are outside his control. The lifetime income stream generated by a particular career depends on the succession of ranks the officer fills. If an officer gets promoted faster, he is more likely to fill higher ranks over a longer career.

If the only effect of graduate education is to raise the promotion rate of officers above what it would be in the absence of that education, it would unambiguously raise the cost of leaving. However, graduate education is also likely to raise the PVC. The present value of civilian compensation depends primarily on the civilian employment. If two officers have the same promotion rate but different levels of schooling, the officer with the smaller amount of schooling is likely to have the longer career length because he has poorer opportunities outside the Navy. Two officers with the same promotion rate and the same amount of schooling may have different expected career lengths if the degree of specificity of the training is different. For example, suppose that technical training in the Navy is more Navy-specific than nontechnical training. If two officers with the same characteristics but different degrees of technical training have different expected career lengths, the technically trained officer has a longer expected career length.

Now consider the effect of different career lengths on the size of the marginal benefit from graduate education. Let $\hat{T}_g$ and $\hat{T}_n$ be the retirement dates for each group. The y_m equation can be rewritten as

$$y_{g,m} = \hat{T}_g - (m - 1 - k)\alpha y_n \tag{25a}$$

and

$$y_{n,m} = \hat{T}_n - (m - 1 - k)y_n \quad . \tag{25b}$$

The marginal benefit equation may be written as

$$MB = MP_1\left\{y_n(\lambda - \alpha)(1 + \beta)^k \sum_{i=1}^{m-k}\left[(1 + \beta)^{i-1}\right] + \left(\hat{T}_g - T_n\right)(1 + \beta)^{m-1}\left(1 - \gamma\right)\right\} \quad . \tag{26}$$

This equation shows that the MB is positively correlated to the change in the length of career weighted by the relative productivity. Clearly, if graduate education leads to a longer career, the marginal benefit is positive. A decrease in the career length does not necessarily lead to a negative marginal benefit, however, because with graduate training an officer is more productive than the officer without such training. The marginal benefit is zero only if the decrease in relative career length equals the relative increase in productivity. For instance, if graduate trained officers are 5 percent more productive than those without such training, but the graduate officers remain in the Navy for 5 percent less time, career length has no effect on the marginal benefit. Even in this case the marginal benefit is positive because the first term in the bracket is still positive.

The following expression, which was derived by setting equation 26 equal to zero, captures the tradeoff between career length and productivity.

$$\hat{T}_n - \hat{T}_g \gtrless MP_1 y_n(\gamma - \alpha) \sum_{i=1}^{m-k} \left[(1 + \beta) - (1 + \beta)^{-m+k}\right] . \qquad (27)$$

If the left side of this expression is greater than the right side, the marginal benefit is negative. Increases in the starting marginal product, the productivity gain parameters b and γ, or the relative promotion rate (i.e., a decrease in α) work to offset decreases in career length that may result from graduate training.

An alternative approach to setting the fixed retirement dates T_g and T_n is to use survival rates to weight the marginal product in each year. The survival rate is the percent of a cohort that remains in the Navy for an additional year. Different survival rates can be calculated for graduate trained officers and for other officers. The advantage of using survival probabilities instead of a fixed retirement date is that the survival probabilities capture some of the dispersion in attrition created by graduate education. Recall that Navy-specific graduate training and rapid promotion lengthen an officer's Navy career, and that general graduate training and slow or lagging promotion tend to shorten a career. Thus, the survival rate for graduate trained officers could fall below that of other officers at some stages of their careers and could raise above it at others.

There is some indirect empirical evidence that the survival curves of the two groups of officers intersect. A study using only Naval Academy graduates found that in the 1947 class the average graduate trained officer remained in the Navy longer than his non-graduate trained counterpart, but in 1950 the opposite was the case. One difference between the two classes is that officers in the 1947 class were more likely to get early promotion to lieutenant commander than in the

1950 class. In other words, among the graduate educated officers, there were more "fast trackers" in the 1947 class than the 1950 class. Getting on the fast track has a greater effect on the length of a graduate trained officer's career than on that of other officers, because the graduate trained officer's opportunity cost of remaining in the Navy is higher. This relationship is better captured by a survival rate approach to career length than by a fixed retirement date approach.

SELECTIVITY BIAS

In the simple model, the selection of officers for graduate study is assumed to be made at random. This assumption implies that the characteristics of the two groups before entry into graduate study are the same. It is made to allow the subsequent performance of non-graduate trained officers to serve as a proxy for the hypothetical performance of the graduate trained group for the calculation of the marginal benefit. This assumption is needed because the hypothetical performance is unobserved, but assuming the two groups have identical characteristics may introduce a bias into the calculation of the marginal benefit. Selection for graduate study is competitive. The number of applicants for graduate study is greater than the number of graduate billets. If the applicant pool reflects the average officer in the Navy, those actually chosen for study would be above average. Using the hypothetical performance of the average officer would underestimate the hypothetical performance of the graduate trained officers, because the average graduate trained officers would perform better even in the absence of such training. This assumption would lead to an overestimation of the marginal benefit of graduate training.

The direction of the bias is not known. For example, suppose that graduate study is viewed as an unnecessary detour on the path to the flag ranks. In this case, the most talented and productive officers, who perceive themselves as having the best chance of making flag rank, may shun graduate study. For other officers, average or below, graduate study may still be viewed as a means of improving the chance for advancement to commander and captain. The upper tail of the talent distribution is cut off from the graduate selection pool. Because the top of the pool is chosen, it is uncertain whether pursuing graduate study has above, below, or just average potential, and the direction of the bias is unknown.

Selectivity bias can be identified if appropriate data are available on the characteristics and performance of officers prior to the time of selection for graduate study. Comparisons can be made between those who were subsequently chosen for graduate study and those who were not. If differences do exist, any further comparisons should attempt to adjust for the bias. Although not all models are amenable to selectivity bias adjustments, the Heckman [5] approach could be adapted to some analysis in this area, such as a comparison of promotion rates. For example, if promotion rates are assumed dependent on personal characteristics, including educational level and performance, performance characteristics can be adjusted using the Heckman technique to eliminate the bias on the educational coefficient in a promotion equation.

DESIGNATOR DIFFERENCES

The officer corps in the Navy is composed of many different occupational groups. Officers are engineers, scientists, doctors, managers, or a variety of other occupations. During an officer's career, he may fall into more than one of these occupational categories. The model as developed to this point assumes that officers of equal ability, rank, experience, and education have the same productivity even if they are in different occupations. Also, the change in productivity over time is assumed to be equal.

This assumption was made initially to simplify the analysis so that the focus could be placed on other issues, but it can be justified on other grounds. The Navy pays all officers of the same rank and years of service the same base pay. If the goal of the Navy is to maximize its productivity given its budget, officers are allocated with equal pay among occupations so as to equalize marginal products across occupations.

There are, however, grounds to criticize the assumption. If the Navy does not maximize output, it may not equalize marginal products. In addition, total compensation, as opposed to base pay, is not equalized because officers in some occupations are paid selective bonuses. Taking these bonuses into account implies that marginal products across occupations may not be equalized.

Given the potential inaccuracy of the assumption of equal marginal productivities across occupations, it is useful to consider the effect of these differences on the marginal benefit functions. This discussion is limited to differences across only broad designator classifications; officers typically remain in a designator group for substantial portions of their careers. Differences in productivity by designators could be introduced into the model in three ways. First, the initial productivities or MP_1's could be assumed to be different across designators. Second, the β parameters, which reflect growth in productivity with rank, could be assumed to be different. Third, the γ parameter, which measures differences in productivity between the graduate and non-graduate trained officers, could be different. An increase in any one of these three variables increases the size of the marginal benefit.

The significance of this result is that the optimal amount of education could vary across designators. Other things equal, the Navy may have more to gain from providing graduate education in some areas more than in other areas. Of course, the optimal level of education depends on both marginal benefits and marginal costs. No conclusions about the optimal amount of education can be drawn from this analysis, because differences in productivity is an empirical issue that goes beyond the scope of this memorandum.

THE MARGINAL BENEFITS FUNCTION

The marginal benefit model proposed earlier measures the gain in productivity of an individual officer resulting from graduate study. The purpose of this model is to help the Navy decide whether to provide more or fewer officers with the opportunity of graduate training. The proposed model is incomplete, because it does not consider how the marginal benefit changes as additional officers receive graduate training.

If the number of officers receiving training is the horizontal axis and the marginal benefit is the vertical axis, the marginal benefit curve slopes downward because of diminishing returns. Each new graduate trained officer increases the overall productivity of the force, but the first group receiving such training is likely to receive billet assignments for which graduate training has the largest effect. As the size of a graduate class increases, the opportunities for large productivity increases are likely to decrease; consequently, the marginal productivity gain from education falls. This results in a fall in the marginal benefit.

Another reason why the marginal benefit curve slopes downward is that not all officers are equally able to assimilate and apply the lessons of the education. As graduate programs increase in size, less able students are admitted and smaller benefits accrue to the Navy.

One factor that may influence the slope of the marginal benefit curve is the steepness of the pyramid of billets by rank. Graduate training improves an officer's relative productivity. For example, suppose that 80 percent of lieutenants get promoted to lieutenant commanders. If an officer is not in the top 80 percent, he does not get promoted. Suppose an officer who would not get promoted otherwise is given graduate education that gets him promoted. As the number of officers receiving graduate education increases, however, the probability that the graduate education leads to faster promotion diminishes, and so the expected marginal benefit diminishes. The diminishing marginal benefit curve λ_i is a function that measures the steepness of pyramid. Because each higher rank has fewer and fewer billets and as more and more officers receive graduate training, fewer of those receiving the training get to a higher rank as a result, so the marginal benefit diminishes. If there is a sharp fall of the pyramid (i.e., a small λ), the marginal benefit has a steep slope, but if there is a gradual fall off (i.e., a large λ), the marginal benefit has a flatter slope. Because the λ_i's vary across designator, the shape of the marginal benefit function might well be different for different designators.

The location of the marginal benefit curve depends on all the factors that influence the individual officer's marginal benefit. These include the initial marginal product, the relative productivity measures, the promotion rate, and the relative career length $(T_g - T_n)$. Increases in these variables cause the marginal benefit curve to shift outward. If all other things are equal (i.e., the marginal cost curve is fixed), the outward shift in the marginal benefit curve increases the optimal amount of graduate education for officers.

MARGINAL COSTS

The marginal cost of graduate education for the Navy is the cost of providing an additional officer with the training. It has three components: the cost of operating the school, the cost of sending an officer to school, and the subsequent changes in salaries resulting from graduate training. The marginal cost of operating the school includes only those costs that change as the school increases in size. The costs of buildings and other capital equipment are included only if additional enrollment or programs necessitate an expansion in capacity. The costs of actually operating the facility, such as for electricity and other utilities, are included in the marginal cost, and these costs may increase with each student. The cost of the faculty of the school is included in the marginal cost only to the extent that increased enrollment leads to an increase in the size of the faculty. When a new program is started, the costs of both facilities and faculty are attributed to the marginal cost of the first student. Expansion of the program from the initial student to its capacity entails near-zero facility and faculty costs.

The second component of the marginal cost is the personnel costs of the students. When an officer is in graduate school, he is paid his normal Navy pay and allowances. While he is in school, he may be producing little or nothing of current value to the Navy. Generally, schooling is a time of investment in future productivity, and most produce little of current value. In this case, the full amount of the pay and allowances should be reflected in the marginal cost. At the Naval Postgraduate School, however, officers in graduate training study problems dealing directly with the Navy's mission. In some cases, the student officers have solved these problems or found improved methods of operation. Although these suggestions cannot be predicted with certainty, they occur with enough regularity that they should be factored into the marginal cost. In other words, student projects may be a part of the research and development processes of the Navy; so the expected value of student research projects should be deducted from the salary in calculating the marginal cost. There are two reasons for including the value of student research projects in this analysis. First, without considering the productivity of students, the optimal level of graduate education is underestimated. Second, if there are significant differences in the value of these suggestions across courses of study, there could be significant differences in the amount of a particular type of training that should be provided.

The third component of the marginal cost is the change in salaries paid to graduate trained officers after they complete their studies. The discussion of the marginal benefit notes that providing graduate education is likely to change officers' career paths. If graduate trained officers are promoted earlier, are promoted to higher ranks, and remain in the Navy longer, they are more costly to the Navy because pay and allowances are higher. This increase in pay and allowances is a consequence of the graduate training and needs to be included in the marginal cost.

IMPLICATIONS

Determining the optimal investment by the Navy in graduate education involves setting marginal benefits equal to marginal costs. Although in principle this may be simple and straightforward, in practice it is nearly impossible. The measurement of both the marginal benefits and the marginal costs requires the measurement of the value of officers' productivity or their marginal product. Because there is no known technique for measuring officers' marginal products, measuring marginal benefits and marginal costs is problematic. The message of this memorandum, however, is that although it may be impossible to determine the precise optimal, there are questions that can be answered and could help improve the allocation of educational resources in the Navy.

The basic point of the marginal benefits model is that much can be learned by examining the relative productivity of officers in different groups. Although the marginal product may not be directly observable, if graduate trained officers can be shown to be relatively more productive than other officers, that difference is proportional to the marginal benefit. A number of variables such as promotion rates and retention rates are readily observed, and comparisons between the two educational groups can be made.

Both the marginal benefit and marginal cost models suggest that another area of study is the allocation of educational resources among various occupational or designator groups within the Navy. For example, if, other things being equal, officers in one designator (A) have larger increases into promotion rate than officers in another group (B), a larger share of educational resources should be allocated to officers in designator A. On the cost side, if there are significant differences among designators in the productivity of the student research projects, the resulting decrease in marginal cost for that group implies that more resources should be devoted to that program.

The analysis in this memorandum may also be used to evaluate the criteria for selection for graduate study. The marginal benefit is modeled as the gain in the value of productivity resulting from graduate education. Selection for graduate study should be based on the potential to increase productivity, where productivity gains could be reflected by intrarank improvements, faster promotion, and longer careers. There are four admissions criteria for graduate training programs. Officers are chosen based on their professional performance, promotion potential, academic capability, and educational foundation for advanced study. The first two criteria relate to the officer's past and future productivity in his Navy duties, and the last two relate to his potential to gain from the graduate training.

By using past performance as an admission criterion, the Navy leadership is showing a willingness to divert some of their best officers from currently productive positions in an effort to enhance their future productivity. In some sense, it places an extra burden on graduate education because the value of these officers to the Navy is the highest. If past performance is a good predictor of future performance, however, such an investment can be worthwhile. Promotion potential is a sensible selection criteria for a number of reasons. An officer who does not get promoted regularly is more likely to leave the Navy. Once he leaves, the Navy has no chance to earn a return on its investment in the graduate training. In addition, an officer with graduate training who does not get promoted is more likely to leave the Navy than a similar officer without the graduate education. Thus, by selecting officers who are likely to get promoted, the Navy is avoiding the situation where graduate trained officers have strong incentives to leave. Also, if officers at higher ranks have more opportunity to be productive than those of lower ranks, promotion is likely to enhance the size of the return. If officers with better past performances and more promotion potential are admitted to graduate study, it is more likely that correction for selectivity bias in measuring marginal benefits is necessary.

Past academic background and performance are also sensible selection criteria, because the ability to gain useful knowledge depends on both innate ability to learn and the person's educational foundation. In the benefits model, these factors are part of the educational production function described in equation 18. Officers with superior past academic performance are likely to generate larger gains (i.e., marginal products of schooling) than other officers. The addition of further criteria for selection may be deemed appropriate after a further understanding of the empirical basis of the marginal benefit is developed.

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